Chapter 6

Isotopic and Elemental Chemistry of Teeth: Implications for Places of Birth, Forced Migration Patterns, Nutritional Status, and Pollution

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Introduction

Concerns about individual and group origins are central to the study of the New York African Burial Ground (NYABG). A key goal of the project is to provide scientific insights into the geographic origins of individuals. Enslaved Africans came from different regions of Africa. Can we determine more precisely the geographic area where individuals and groups come from and what were their ethnic affinities? At what ages were enslaved individuals forced to involuntarily leave their homelands? Which individuals came to New York via the Caribbean or some other destination in North America? Who was first generation enslaved, and who was born into slavery?

Although origin questions are central to this project, providing insights into origins is difficult. To date, few methods provide clear answers. Historical documents such as slave ship manifests and auctions provide an overall and indispensable source of information on geographic origins, ethnicities, demographic patterns, and even names (e.g., see Gomez 1998; Hall 1992; Lovejoy 1997, 2003). However, there is no method we are aware of that can link these historical records to individual burials.

Archaeological information such as artifacts and burial position may suggest an individual's natal home (geographic place of birth), possible ethnic affinity, or status within an enslaved community (Corruccini *et al,* 1987a; Handler 1997; Samford 1994).

However, because cultural practices, such as placing a burial in extended position or facing east, are generally without fixed temporal and spatial boundaries, suggestions as to geographic and ethnic origins must be appropriately broad and speculative (DeCorse 1999) and sensitive to the fact that such practices potentially convey multiple messages (Perry and Paynter 1999).

Information derived from bones and teeth, that is, bioarchaeological information, may similarly provide insight into geographic and ethnic origins. Genetic information derived from bone and tooth size and shape, and more directly, from mitochondrial DNA (mtDNA) provide a means to compare an individual or group with values from contemporary "ethnic groups" (see Chapter 5; Watson et al. 1996; Jackson 1997). The resulting data provide insights into genetic, and by extension, ethnic affinities. While extremely powerful, these methods are also limited. Because humans historically do not live in closed communities, genetic traits and frequencies are fluid, open, and not culturally bounded. As well, the relationship between genetic affinity and ethnicity may change over time because of group fissioning, exogamy, and the fluidity of ethnic categories (Goodman 1997).

Other types of bioarchaeological information may provide insights into natal homes and ages at forced migration. For example, death in the first decade of life suggests that an enslaved child was born in the Americas versus Africa or the Caribbean because historical documentation shows that enslaved African New Yorkers were most often "*young adults from whom the buyer could expect many years of service*" (McManus 2001[1973]: 36; see also Lydon 1978). Corruccini et al. (1987b) suggest generalized tooth root hypercementosis associated with seasonal "rehabilitation" following cycles of

poor nutrition throughout most of the year may distinguish Caribbean-born from African-born individuals among an enslaved population in Barbados.

Conversely, Handler (1994) has suggested that culturally modified teeth (CMT), teeth that have been intentionally and decoratively chipped, filed or otherwise modified, in enslaved Africans in the Americas, is a marker of African natality. Permanent teeth begin to erupt after about six years (Smith 1991), and historical documentation of CMT in Africa consistently shows that the practice was most often performed on individuals approaching their teens and older (van Rippen 1918). More important still, Handler (1994) makes a strong case for the assumption that this cultural practice was discontinued under enslavement in the Caribbean and the Americas. In this chapter, we provide two pilot chemical tests of the hypothesis that young individuals were born into slavery and individuals with culturally modified teeth were enslaved in Africa.

One of the most exciting technical developments in analytical chemistry is the maturation of multiple techniques for analysis of the geographic origins of humans and other organisms with sequentially calcifying tissues such as fish otoliths and human teeth (Campana et al. 1994; Cox et al. 1996; Evans et al. 1995; Lee et al. 1999; Lochner et al. 1999; Outridge 1996; Outridge et al. 1995). At the time of rediscovery of the burial ground, chemical ecology studies were just beginning to show that strontium and oxygen isotopes in hard tissues reflect landscapes during their calcification and that each landscape has a somewhat unique elemental and isotopic signature (Ambrose 1991; Blum et al. 2000; Ericson 1985, 1989; Larsen 1997; Price et al. 1994a, 1994b; Schwarcz et al. 1991; Schwarcz and Schoeninger 1991; Sealy et al. 1991, 1995; White et al. 1998; see Figure 1). Emerging with the development of studies of enamel, which forms in early

life, these new techniques provided the first unambiguous methods for reconstructing human landscapes at the time of birth and through the first decade (Cox *et al*. 2001, Cox and Sealy 1997; Grupe 1998; Gulson *et al.* 1997; Sealy *et al*. 1995).

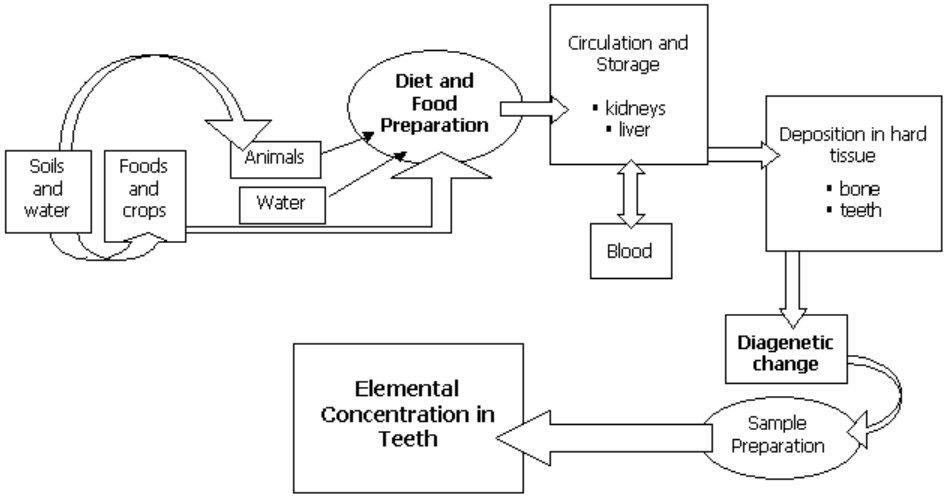

Figure 6.1: Elemental Uptake/Deposition Model

The ability to track individuals' natal homes and then their ages at movement from their places of birth is based on the fortunate co-development and intertwining of three advancements:

- Better understanding of the geology and chemical ecology of landscapes.
- Better understanding of patterns of calcification of dental enamel, dentin and cementum.
- The development of chemical analytical methods that allow for the "microsampling" of enamel and other hard tissues.

The hard tissue samples provide a chemical signature of individuals at different ages at development. With samples taken from sequentially developing areas, one can track

changes over the life of an individual. Cementum provides information on annual changes (Evans et al. 1995; Hals and Selvig 1977; Tsuboi et al. 2000), whereas primary enamel and dentin can provide a chronology of change in early years and months.

The purpose of this chapter is to present results from our ongoing research on the use of multiple chemical methodologies to provide insights into the geographic origins and ages at migration of individuals from the NYABG. The first part of the chapter provides an overview of chemical methods that are relevant to a full study of geographic origins, ages at migration, nutritional status and pollution exposure. In the second section, we provide detailed methods and results of research that has been completed thus far on strontium isotope ratios and variation in multiple elemental concentrations, or elemental signature analysis (ESA). We then compare the chemical signatures of individuals assumed to be African born via the presence of modified teeth with individuals assumed to be born around New York because of their young age at death. We highlight an unexpected finding: that lead concentrations are significantly elevated in the individuals who were born in New York and that these elevations appear to begin in the first years of life. Finally, we discuss the implication of the completed research and the benefits that would accrue from additional research.

Tooth Development and Chemistry

Teeth contain unique information about past environmental and physiological conditions. The pattern of formation of enamel and dentine is clearly demarcated and ring-like, much like the rings of trees (Kreshover 1960; Goodman and Rose 1990) or more so, the leaves of an onion or artichoke. Furthermore, once formed, the dental hard tissues, and especially enamel, which is acellular and nearly totally mineralized, are

essentially inert (Carlson 1990). Earlier in this century, Massler et al. (1941: 36) confidently stated: "enamel and dentin in the formative and calcifying stages of their growth serve as kymographs on which are permanently recorded physiologic or pathologic changes in metabolism."

The potential of the dental hard tissues continues to be echoed through the second half of the twentieth century. In 1988, Sharon advocated for a scientific "tooth bank" because *"Teeth are storehouses of invaluable information for biological, physical, and medical sciences. . . . Teeth can provide keys to provenance, development. . . . exposure to pollutants and provide a permanent cumulative, qualitative, and quantitative record of insult"* (1988:124). In a commentary in *Science* on the developing field of biogeochemistry, Kohn (1999:335) notes that "enamel retains an exquisite microstructure produced when the animal precipitated its tooth and is the material of choice for terrestrial studies." All authors assert that with further research, teeth will yield information applicable to a wide variety of environmental and biological questions.

Indeed, teeth have begun to yield insights about life conditions during their formation. Starting with the work of Massler and colleagues (Sarnat and Schour 1941), many researchers have evaluated variations in enamel's external morphology and histological structure in relationship to histories of disease and other conditions that might disrupt development (see chapter 9). These studies have shown that linear enamel hypoplasias, lines or bands of decreased enamel formation, are linked to a wide variety of conditions that are sufficiently severe and long lasting to disrupt ameloblasts, the enamel forming cells (Goodman and Rose 1990). Furthermore, the location of these defects on tooth crowns reflects the timing of the physiological disruption (Sarnat and Schour 1941;

Goodman and Song 1999). The sensitivity of ameloblasts to physiological conditions, enamel's inertness once formed, and the ability to discern the timing of disruption from their location make linear enamel hypoplasias biological records of past physiological statuses (see Chapter 8).

In a prior study of the burial ground, Blakey (1998a) used enamel hypoplasias recorded on the teeth of adults as an index of childhood conditions (permanent tooth crowns develop from ~birth to ~seven years of age). They found a moderate rate of enamel defects compared to Caribbean slaves (Corruccini et al. 1985), suggesting less stress in childhood. However, these preliminary results are complicated by the fact that many of the adults may have grown up in Africa, rather than as enslaved Africans in New York. Tooth chemistry may be able to resolve who grew up in the New York area, somewhere in Africa, or a third location such as the Caribbean. Furthermore, taking advantage of the different times of calcification of different teeth and regions within a tooth, it may be possible to estimate the age of individuals at the time of forced migration or any other geographic relocation.

Indeed, analyses of the chemical composition of dental tissues may provide new and complementary insights into (1) hard tissue chemistry and development, (2) diet and nutritional physiology, (3) the movement and migration of individuals, and (4) diverse environmental conditions such as industrial lead production. For example, paleonutrition, the study of the diet and nutrition of past peoples, emerged in the 1970s from developments in the chemical analysis of bone, combined with an understanding of ecological and physiological processes governing the deposition and retention of elements in calcified tissues (Aufderheide 1989; Price et al. 1985). The promise of this

field is that isotopic and elemental concentrations in preserved hard tissues would reflect aspects of dietary intakes or nutritional status. Recent developments are just now beginning to suggest that the potential of chemical studies of teeth may be reached. Relative to morphological and histological analysis, this delay in maturity of this field is based on at least three factors.

- First, **bone was initially the preferred hard tissue for study**. However, as results accrued, many researchers began to realize that the processes governing elemental and isotopic incorporation and turnover of bone (and in the case of archaeological bone, postmortem changes) were more complex than previously realized.
- Second, until recently, **methods were not widely available to chemically relate areas of enamel to known periods of development** (prenatal, early infancy, childhood, etc.). The development of microsampling methods, and in particular laser ablation analysis, which is keyed to the ring-link development of enamel and dentine, is now solving this second problem (Outridge 1996).
- Third, interpretations of bone elemental values are limited because of **lack of background information** and **lack of controlled studies** of ecological, physiological and biochemical processes. Although enamel offers important advantages of highly regulated calcification geometry and inertness once formed, our understanding of the significance of its elemental concentrations remains rudimentary for the same reasons.

The Histology and Development of Dental Calcified Tissues

Human teeth consist of three hard tissues: enamel, dentine, and cementum (Figure 6.2). Enamel forms the exterior of the crowns of human teeth; dentine

comprises the interior of the crown and roots, and a thin layer of cementum covers the roots. In addition to the "primary" cementum and dentine, which is formed during early in life, secondary (circumpulpal) dentine and secondary cementum are continuously deposited.

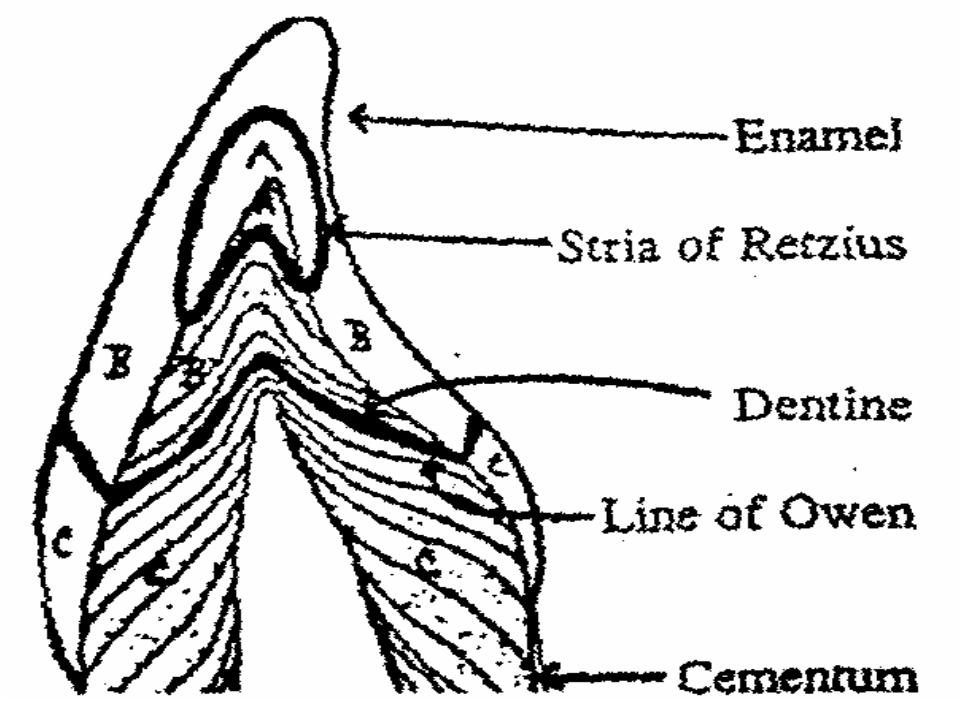

Figure 6.2: **Longitudinal cross section of a deciduous incisor tooth showing enamel dentine and cementum. Zones A, B, and C in enamel and dentine represent the earlier to later calcifying portions of the tooth crown. The pattern of formation is reflected in contour lines of Owen in dentine and stria of Retzius in enamel. The accentuated growth line between zone A and B is the approximate division between the second and third prenatal trimester, and the line between zones B and C represents the approximate location of the birth line. Acid dissolution may sample zones of "dome" enamel whereas laser ablation samples finer areas of enamel and dentine.**

A summary of variations among the dental hard tissues and bone is presented in Table 6.1. Some key differences are the hardness of enamel and its lack of regenerative (turnover) abilities.

Table 6.1: Comparison of Dental Hard Tissues and Bone.

	Enamel	Dentine	Cementum	Bone
Origin	Ectoderm	Ectomesenchyme	Mesoderm	Mesoderm
Organic framework	Pseudokeratin	Collagen	Collagen	Collagen
Crystal	Apatite	Apatite	Apatite	Apatite
Internal cell space	None	Dentinal tubule	Canaliculi	Canaliculi
Turnover Ability	None	Odontoblast	Cementoblast	Osteoblast
Chemical Composition (Ave.)				
Organic	0.3%	15%	23%	21%
Inorganic salt	97.2%	75%	65%	65%
Water	2.5%	10%	12%	14%

Enamel

The hardest and one of the most specialized tissues in the body, enamel covers the crowns of teeth (Figure 6.2). The thickness of the enamel layer ranges from less than 0.1 mm near the cervical border of deciduous teeth to a few millimeters on the crowns of permanent molars. Enamel is formed from ameloblasts that derive from the inner enamel epithelium. After odontoblasts begin secreting the dentine matrix, adjacent ameloblasts quickly begin secreting enamel matrix. Once the full thickness of enamel matrix is

reached, ameloblasts change morphology and physiology consistent with a change in role from matrix secretion to absorption of protein and water and calcification. After enamel is fully calcified, ameloblasts become senescent; mature enamel is an acellular and essentially dead, 97 percent calcified tissue. The temporal record of past physiology and chemistry may be seen to follow the enamel growth lines, stria of Retzius (Figure 6.2). Enamel is the tissue of choice for our research because its formation is well understood and it is acellular, nonvital, and nearly completely composed of apatite crystals (Cleymaet et al. 1991).

Dentine

Tooth formations begin with the secretion of predentine by odontoblasts, dentine forming cells. Dentine formation is highly regulated and occurs in layers or sheets, as odontoblasts are recruited to secrete dentine matrix. The pattern of formation of dentine is visible in growth lines called contour Lines of Owen (Figure 6.2). Dentine calcification occurs relatively quickly after the collagenous dentine matrix is formed. Like all other calcified tissues, apatite is dentine's main crystal component (Ten Cate 1985).

A small amount of secondary (or circumpulpal) dentine is continuously deposited after eruption. Chemical characterization of this dentine is useful as a referent for average conditions over a long span of time, such as long term lead exposure (Needleman and Bellinger 1991).

Cementum (or cement) is a thin covering of the roots of teeth. It is relatively similar to bone in a number of respects, including embryological origin, basic structure and degree of calcification. Its apatite crystals are similar in size and structure to bone and dentine,

about 200-1000 angstroms in length and 30 angstroms in width (Carlson 1990). One notable feature of cementum is that in addition to a primary layer in mammals, it is continuously deposited in annual rings, which has been used in wildlife biology and bioarchaeology as a method for determining age at death (Charles et al. 1986, Condon et al. 1986; Kagerer and Grupe 2001). Because of its continued deposition, cementum chemistry provides a means of tracking annual life history changes until death. Outridge et. al (1996) have shown that lead varies by cementum layers (Figure 6.3).

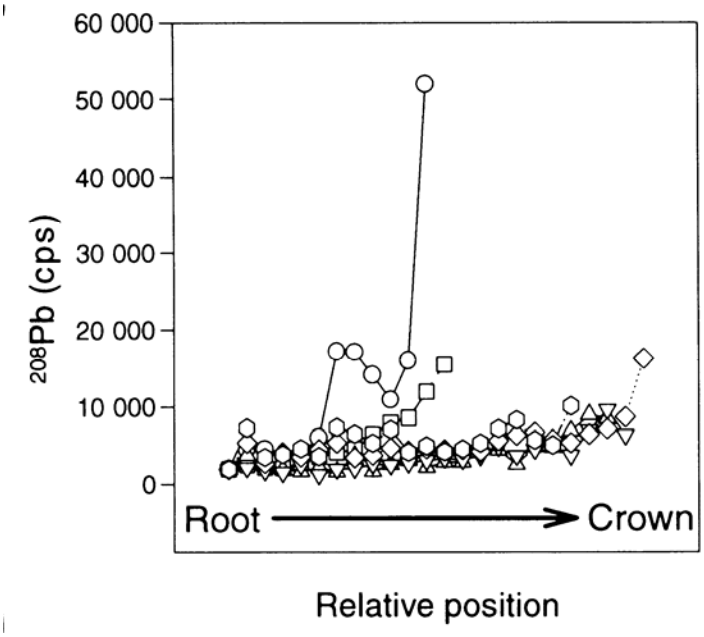

Figure 6.3: **Outridge and co-workers (1996) were the first group to use LA-ICP-MS to study chemical changes in teeth, In this figure (Outridge *et al.*, 1995: 167) they illustrate changes in ^{208}Pb content of six adjacent annual cement rings of a walrus tooth (Pb is estimated as counts per second). Each layer is represented by a different symbol, with 11 to 20 ablation areas per layer. A spike occurs in one layer; however, the lead content is quite variable. Because human cementum is very thin and more vital that enamel and dentine, we have not chosen to focus on it. However, if time permits, we will pilot a laser ablation study of human cementum.**

Instrumentation and Methods of Analysis

One of the challenges of hard tissue chemical studies is to be minimally destructive and at the same time provide chemical information based on the pattern of development and calcification of enamel and dentine. Until the last few years, two general methods have been used to analyze lead and other elements in dental samples: digestion of whole teeth or major portions for wet analysis and surface profiling. Neither method provides much needed time-specific information. However, in recent years, techniques that do so have come to maturation. These involve either 'ablating" or microdrilling small areas of hard tissue. We have employed laser ablation to provide elemental information and drilling to provide information on isotopes. The following is a brief description of the instrumentation, coordination of activities, the utility of each methodology, and an overview of the main questions to be addressed.

Instrumentation and Coordination of Samples

Elemental analyses have been carried out utilizing Hampshire College's Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Perkin Elmer Elan 6000A; Shelton, CT) and attached Laser Ablation system (CETAC LSX 100, Omaha, NE). The marriage of the high precision, high sensitivity, and multi-element capacities of a state-of-the-art ICP-MS with the spatial resolution capabilities of laser ablation (LA-ICP-MS) provides us with a unique opportunity to construct detailed maps of elemental concentrations in teeth with minimal sample preparation and minimal destruction. The method is particularly ideal for chronologically developing tissues such as trees, shells, and teeth (Outridge 1996). Our laser ablation system was obtained to study hard tissues.

Tooth samples have also been prepared at Hampshire College and then are sent to other laboratories that specialize in isotopic analyses. In the early stages of research, samples were removed using a Dremel Drill (see Figure 6.8). The results presented below on strontium isotopes are based on enamel and dentin removed by this method and analyzed at the University of Kansas by Doug Walker. In May 2002, we obtained a precision micromill (New Wave Research), allowing us much better control of the location and size of the sample. For example, the micromill allows us the potential to sample multiple isotopic systems at dozens of locations within a single tooth.

The Chemical Tool Kit

The major dietary methods are presented first: elemental strontium, barium, zinc, iron and carbon and nitrogen isotopes. These are followed by methods for evaluating environmental change: elemental signature analysis (ESA), oxygen isotopes and strontium isotopes, and finally, methods that indicate pollutant exposure and ingestion (lead, arsenic, mercury, etc.) that might also imply location via anthropogenic sources. We wish to eventually employ multiple chemical methods in order to obtain multiple confirmations of origins and nutrition. However, due to funding limitations, here we focus on results obtained thus far for three methodologies that relate to origins and anthropogenic pollution: elemental signature analysis, elemental lead, and strontium isotope ratios.

Strontium and Barium

Studied relative to calcium concentrations, strontium and barium concentrations provide a means for evaluating the trophic level of diets. Strontium (Sr) and barium (Ba) substitute for calcium (Ca) in hydroxyapatite, the major inorganic component of all hard

tissues. However, calcium is "favored" or enriched over the other two divalent cations because of its smaller size. An enrichment or fractionation step occurs as food moves through trophic levels (Figure 6.4). Therefore, herbivores have more strontium and barium relative to calcium than primary carnivores, which have more strontium and barium than secondary carnivores. Thus, ratios of strontium and barium to calcium have become well established as indicators of the relative portion of meat in diets (Ambrose 1993; Blum *et al.* 2000; Burton and Price 1990; Gilbert et al. 1994; Runia 1987; Sealy and Sillen 1988; Sillen and Kavanagh 1990).

Because breast-feeding is a higher trophic level than weaning, an increase in strontium/calcium and barium/calcium ratios in teeth may also be used to pinpoint the age at weaning (Katzenberg et al. 1996). Here, LA-ICP-MS is a particularly excellent methodology. It is one of just a few instruments that can measure strontium and barium in small, targeted samples with the needed sensitivity and can evaluate change in elemental ratios virtually by week (LA spot size can be as small as 10 μm, which is equal to about 2-3 days of enamel development.)

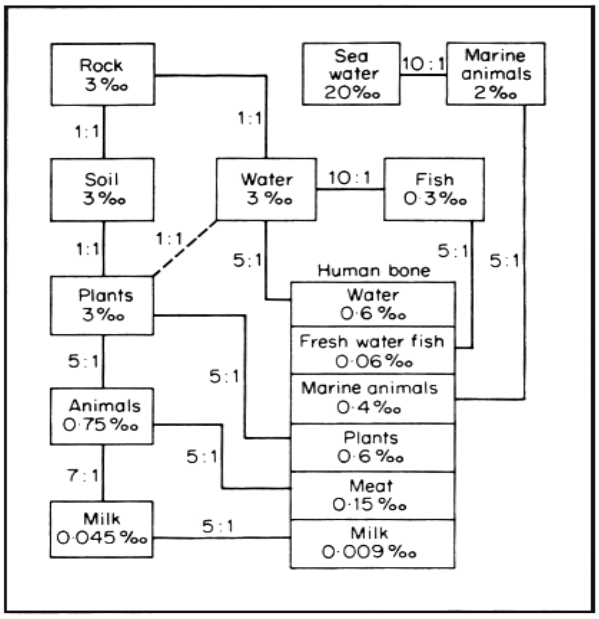

Figure 6.4: Diagram from Price *et al.* (1985: 423) showing the five-fold fractionation of Sr/Ca occurring during human digestion, and the contributions to the composite Sr/Ca of bone from various diet components. With knowledge of environmental levels of Sr and Ca and of fractionation dynamics, one can balance the relative input of Sr and Ca into bone or other calcified tissues. Ezzo (1994a; 608) suggests that strontium "is the only firmly established elemental model in bone chemistry analysis." Yet, this is not a simple system, nor has it been fully tested for either bone or dental hard tissues. We propose to test various links in the Sr system and also to use this diagram as a model for study of other systems such as Fe, Ba, Sr and Pb.

Zinc and Iron

Zinc and iron are essential elements that are frequently deficient in diets. Their deficiency may cause a wide spectrum of functional consequences. Both nutrients are key to maintaining linear growth and resistance to infectious disease. Iron also affects cognitive development and work capacity. Although the consequences of these micronutrient deficiencies are often masked by protein energy malnutrition, deficiencies in these two elements can have severe consequences for the individual, the family and the social group (Allen 1993; Anonymous, 1979; Golden 1988; Scrimshaw 1991). Contemporary diets are frequently deficient in one or both of these micronutrients

(especially when dietary diversity is low, and meats and fresh fruits and vegetables are limited).

It is highly likely that zinc and iron deficiency were prevalent and consequential to the lives of the enslaved Africans, and it is also likely that their consequence may have been masked by gross protein-energy deficiency. Thus, direct measurement of iron and zinc concentrations will supplement prior analyses of porotic hyperostosis (an indicator of iron deficiency anemia) and bone growth (reflecting overall nutritional status).

Since the 1970s, these elements have been studied in bones and, more recently, in teeth. Ezzo (1994b) warns that interpretations are not unambiguous. We have studied zinc concentrations in deciduous teeth of contemporary Mexican children with known diets during their tooth formation. Our main finding is that enamel zinc concentrations are not related to total zinc intake, but they are strongly associated with factors affecting bioavailability such as phytate and calcium intake (Goodman et al. 2003).

Carbon and Nitrogen Isotopes

The combined analyses of stable carbon isotopes on enamel carbonate, bone carbonate, and bone collagen (respectively, mineral and organic fractions of bone), and nitrogen isotopes on bone collagen, provide data on the macronutrient components of diets, as well as, the degree of herbivory versus carnivory. This method can provide distinctions between consumption of different plant groups (e.g., maize vs. most other plants), terrestrial, freshwater, and marine resources, and legumes versus other plants. This analysis will: (1) help to refine understanding of nutritional (and possibly infectious) diseases in individuals, (2) provide a means of looking at social differences within and between groups, and (3) document major dietary shifts which can be caused by

geographic relocation. As well, paralleling the analysis of oxygen isotopes (described below) and changes in strontium and barium relative to calcium, nitrogen isotopes can distinguish nursing infants who are one level higher in the food chain than their mothers (Katzenberg et al. 1993; Schurr 1997). Lastly, this isotopic data will be integrated with the elemental data (iron, zinc, strontium, barium, etc.) from the same tissues to refine our reconstruction of food consumption and nutritional status.

Elemental Signature Analysis (ESA)

The ICP-MS allows for the simultaneous analysis of a wide suite (~ 90) of elements and their isotopes in semi-quantitative mode (Table 6.2). This methodology provides a rapid assessment of the presence of pollutants and additional elements of possible interest, especially those that might be useful to discriminate subgroups (such as those who grew up in New York versus elsewhere). For example, results from this mode of analysis may be analyzed with discriminant function or cluster analysis to identify groups of individuals and outliers who may be migrants. ESA will complement more specific methods noted below for evaluating migration and change in environment.

Table 6.2: Range of Element Concentrations in Human Dental Enamel. Elements in bold are research foci. A suite of elements will be used in some studies.

Concentration range in ppm	Elements
> 1000	Na, Cl, Mg
100-1000	K, S, Zn, Si, **Sr**
10-100	Fe, Al, **Pb**, B, Ba
1-10	Cu, **Rb**, Br, Mo, Cd, I, Ti, Mn, Cr, Sn
0.1-0.9	Ni, Li, Ag, Nb, Se, Be, Zr, Co, W, Sb, Hg
<0.1	As, Cs, V, Au, **La**, **Ce**, Pr, Nd, Sm, Tb, Y
Modified from Curzon (1983: 5).	

Strontium Isotopes

The isotopic composition of strontium is widely used in the earth sciences to discriminate between differing geologic terrains and, as a result, may be valuable in tracing the places of birth and early life of the enslaved African. Strontium, which has chemical affinities to calcium and concentrates with calcium in hard tissue, occurs as four stable isotopes, ^{84}Sr, ^{86}Sr, ^{87}Sr and ^{88}Sr. ^{87}Sr is the decay product of the long-lived radioactivity of ^{87}Rb; with time, the proportion of ^{87}Sr to total Sr grows at a rate dependent on the available Rb. Geologic environments rich in Rb relative to Sr will undergo large increases in the ratio $^{87}Sr/^{86}Sr$, while regions of the earth with low Rb/Sr ratios will retain low values of $^{87}Sr/^{86}Sr$ for long periods of geologic time. Since Rb is a particularly weak bonding element in the high temperatures of the earth's interior, it has been flushed to the surface through volcanic activity over time and has been concentrated in the continental crust. Stronger bonding Sr is less fractionated and remains in higher concentration in the earth's interior. As a result, old continental rocks have developed high $^{87}Sr/^{86}Sr$, while volcanic islands recently formed by partial melting of the Rb-poor mantle of the earth have dramatically lower $^{87}Sr/^{86}Sr$. The $^{87}Sr/^{86}Sr$ ratios in teeth and bones of humans whose food and water are locally obtained should reflect the $^{87}Sr/^{86}Sr$ ratios of their environment.

Continents typically consist of regions of ancient rock (cratons) stitched together by zones of younger mountains created during relatively more recent continental collisions. West Africa is typical in that a zone of approximately 600 million year old mountains (in Nigeria) lies between very old (more than 2 billion years) cratons to the west and to the south. $^{87}Sr/^{86}Sr$ in the cratons will be very high, while the mountains

created in more recent time will have a contribution from the earth's interior and have lower $^{87}Sr/^{86}Sr$. The strongest potential differences in $^{87}Sr/^{86}Sr$ will exist between the cratons of Africa (with a $^{87}Sr/^{86}Sr$ ratio often above 0.80000) and the young volcanic rocks of the Caribbean, particularly the modern volcanic rocks of the outer Antilles (with $^{87}Sr/^{86}Sr$ ratios in the range of 0.7020-0.7040).

Cuba, Dominica, and the western islands of the Caribbean have a continental component and should be distinguishable from the younger, more fully mantle-derived volcanics of the outer Antilles. Since modern $^{87}Sr/^{86}Sr$ analytical procedures produce ratios that are resolvable to the sixth figure beyond the decimal place, there is great potential for finer discrimination among populations. Figure 6.5 provides a general sense of the geographic pattern of strontium isotope ratios.

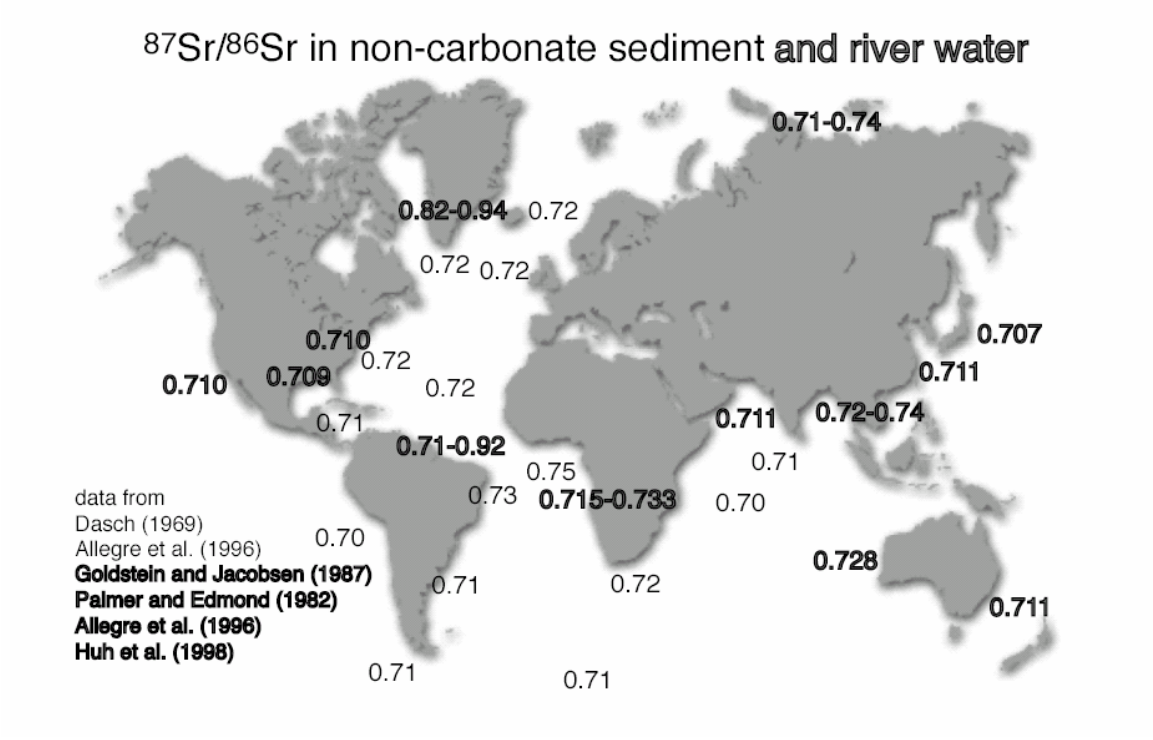

Figure 6.5: Broad geographic pattern of strontium isotope distribution.

As with the other "provenance" methods, analysis will focus on a life span perspective with separate analyses of bone and different teeth and parts of teeth that calcify at different times in life. Thus, it may be possible to pinpoint the age of any individual at time of movement from one location to another, and any subsequent movement.

Oxygen Isotopes

Oxygen isotope analysis has recently been developed for bone and enamel phosphate (Wright and Schwarcz 1998; White 2002). In contrast to carbon isotopes, which are based on the premise that "you are what you eat," oxygen isotope analysis is based on the premise that "you are what you drink." Values in our body fluids reflect those of the water we drink, and the values of environmental water are a function of complex physiographic and climatic variables including temperature, humidity, rainfall, distance from the ocean and altitude. By analysis of teeth that have formed at different ages in life, it is possible to estimate the age at which individuals moved from one environmentally distinct region to another. As in other analyses, bone values reflect more recent and last locations.

This methodology has been employed on ice cores from Greenland to plot annual changes in the earth's temperature. Oxygen isotope ratios are sensitive to minor changes in ambient temperature. White et al. (2002) have employed this isotope to discriminate individuals who grew up at Teotihuacán, in the Valley of Mexico, versus those who may have grown up at Monte Alban, Oaxaca and in the Maya highlands further to the south. Oxygen isotopes should distinguish with great fidelity individuals who grew up in a tropical area (West Africa and Caribbean) from those who grew up in a more temperate

zone (New York). In trying to pin down the possibilities of a two-step migration from Africa to the Caribbean to the United States, this method perfectly complements the analysis of strontium isotopes.

Because nursing infants are one level higher in the food chain than their mothers, their oxygen isotopic ratios are enriched. Because the balance of protein, fat, and carbohydrate is unique in nursing children, the difference between the collagen and carbonate values is much smaller than it is in adults in the same population. These techniques allow us to tell how long the nursing period lasted and how prolonged the weaning period was.

Environmental controls, that is, water and tooth samples from current or historical inhabitants of New York and areas where the enslaved African may have lived, are crucial to take maximum advantage of oxygen isotope results. Oxygen isotopes without environmental controls can identify outliers and the number of movements (useful information in itself). But without control data, it cannot identify location of origin. To establish a baseline for the location of an individual, a contemporary or archaeological bone or tooth sample (either human or animal) can be used, along with water samples. Suspected locations of origin would be similarly sampled.

In summary, oxygen isotope analysis, when combined with insights from analyses of ethnohistorical information and other chemicals and DNA analyses, may provide a powerful tool for locating regions from which individuals may have moved. Oxygen isotope analysis can be used to specifically test hypotheses derived from other analyses.

Lead, Lead Isotopes and Heavy Metal Pollution

Lead has frequently been studied in deciduous teeth to track current lead exposures and in bones to provide a history of pollution exposure (Aufderheide et al., 1988; Budd et al. 1998; Fergusson and Purchase 1987; Gulson and Wilson 1994; Purchase and Fergusson 1986; Shapiro et al. 1972). Based on bone lead levels and historical documentation, Corruccini et al. (1987a) suggest lead poisoning from rum intake and inhalation of fumes during sugar manufacturing was an "unrecognized epidemic" in the Caribbean during the seventeenth and eighteenth centuries that would have affected enslaved African and white health and mortality.

By using LA-ICP-MS we can pinpoint the age and chronological nature of exposure to pollutants (Evans et al. 1995; Outridge 1996; Outridge et al. 1995). Such data provide insights into maternal exposure (via analysis of deciduous teeth), occupations, and movement. The analysis of lead isotopes provides a means to evaluate the potential source of lead (as each source has a unique isotopic signature), and this method, too, may be used to evaluate change in location. Gulson *et al.* (1997) found that differences in lead isotope ratios ($^{207}Pb/^{206}Pb$ and $^{206}Pb/^{204}Pb$) of permanent and deciduous teeth enabled distinction between immigrants and long-term residents in Australia, and hypothesized that observed differences in blood-enamel and blood-dentine isotope exchange rates may be used to estimate individuals' residence time in Australia.

Methods and Results

In this section, we first review the working hypothesis that individuals with culturally modified teeth were African born. This hypothesis sets up the expectation that individuals with modified teeth might chemically cluster differently than individuals who

died in the first decade of life and are assumed to be New York born. We then test this hypothesis by elemental signature and strontium isotope analysis.

African Cultural Modification of Teeth

The practice of intentionally modifying teeth spans thousands of years and is geographically widespread. Morris (1998) notes that dental chipping and intentional removal was observed among Early Iron Age (ca. 1500 years B.P.) skeletal remains from southern Africa. Britain, India, China, Southeast Asia, Japan, the Malay Archipelago (including the Philippines and New Guinea), Australia, Oceania, the Americas, Hawaii, Grenada and the Virgin Islands have also produced excavated, culturally altered dentitions (Milner and Larsen 1991). With declining prevalence, members of some societies – notably in Africa, although elsewhere – continue to alter their physical appearances by decoratively filing, chipping, ablating or otherwise modifying dentitions (Milner and Larsen 1991; Inoue et al. 1992, 1995; Jones 1992; Morris 1998). Although culturally (i.e., intentionally and non-therapeutically) modified teeth "indicative of different ways of life" have long interested anthropologists, Milner and Larsen (1991: 357) note that studies tend to be "particularistic, frequently focusing on single specimens or skeletal series from a certain site," and reflective of the discipline's "descriptive phenomenologically oriented tradition." Recent work, however, considers dental modification as a "biocultural attribute" possibly linked to "social distinction" and "cultural integration" at pre-Hispanic Mayan archaeological sites (Tieslerbos and Frausto 2001) and social status among pre-contact Guamanians (Ikehara-Quebral and Douglas 1997).

Anthropologists have offered different explanations linking cultural dental modification and African natality. Stewart and Groome (1968) suggest dental modification would have seemed "hostile" to European slaveowners, who, as a result, would have prohibited its practice whenever possible. Handler and co-workers' (1982) analysis of the late seventeenth to early nineteenth century Newton sugar plantation cemetery in Barbados includes a more complex explanation based on integrated archaeological, bioanthropological and ethnohistorical data. While European traders in West Africa regularly commented on African cultural practices as "heathenish" or "savage," Handler and co-workers (1982) suggest scarce documentary reference to dental modification in colonial settings makes it difficult to reliably assess slaveowners' perceptions of the practice as "hostile" or otherwise problematic. In fact, where dental modification is mentioned, i.e., in runaway advertisements, it is for the purpose of enhancing descriptions of African escapees in order to facilitate their recognition and recapture.

Handler and co-workers (1982), note that runaway attempts were frequent in the Caribbean and other parts of the New World, during this period. Interestingly, they further note that posters to help find the runaways with modified teeth invariably include reference to African natality in the form of cultural attributes such as cicatrization (or "country marks") or through ethnic distinctions (of varying precision) such as "Ibo" or "Coramantine." Handler (1994) offers further support for this hypothesis in the form of similar findings from British colonial North America, noting that contemporaneous runaway advertisements from Georgia, Maryland, Virginia, and North and South Carolina also mention dental modification only with respect to individuals whom slave

owners believed to be African born. Like Stewart and Groome (1968), Handler and co-workers (1982) and Handler (1994) suggest African dental modification indicates African natality, as the practice was most likely discontinued in the Americas. However, following Price and Price's (1972) discussion of cicatrization in Suriname, Handler and co-workers (1982) and Handler (1994) argue that, unlike more easily hidden or coded African cultural practices, dental modification was voluntarily discontinued due to its highly visible, "immutable and indelible" results – i.e., as "an adaptive response" enabling greater anonymity during escape efforts.

If fleeing enslavement was central to cultural reasoning that concluded dental modification was maladaptive in the New World, one might still expect this practice to be more visible in the bioarchaeological record. This is due to the prevalence of dental modification in those areas from which most enslaved Africans were extracted during the period of the trans-Atlantic Trade (see Table 6.3), as well as the fact that *most* enslaved persons apparently did not attempt escape. While Handler and co-workers (1982) correctly note that many did, the majority of enslaved Africans engaged in (often more subtle) forms of resistance such as working slowly, intentionally breaking tools to disrupt production, *or maintaining African cultural practices*. In such contexts, dental modification may have taken on importance as a marker of social identity in the Americas perhaps even more acute than seen generally in Africa, where its meanings were sometimes sacred, but sometimes superficial (van Rippen 1918).

Table 6.3: African Dental Modification Patterns: (Gould et al., 1984)

A. Filing mesial maxillary central incisors (Guinea, Togo, Angola, Democratic Republic of the Congo, Uganda, Kenya and Tanzania)

B. Filing mesial and distal of maxillary central incisors
(Guinea, Central African Republic, Democratic Republic of the Congo, Angola)

C. Filing six maxillary anterior teeth to pointed shape
(Democratic Republic of the Congo, Zimbabwe)

D. Filing four maxillary and four mandibular incisors to pointed shape
(Guinea, Cameroon, Republic of the Congo)

E. Horizontally filing maxillary central incisors
(Guinea, Democratic Republic of the Congo)

F. Centrally notched incisors (Sierra Leone)

G. Serrated incisors (Mozambique)

H. Mesial triangular notch cut in gingival one-third of central incisors
(Republic of the Congo, Sudan)

I. Concave filing of maxillary incisor, convex filing of mandibular incisors
(Tanzania, Mozambique)

J. Extracting maxillary central incisors (Zambia)

K. Extracting mandibular central incisors (Uganda, Kenya)

L. Extracting primary mandibular canines
(Democratic Republic of the Congo, Sudan, Uganda)

M. Extracting four maxillary incisors (South Africa)

N. Extracting four mandibular incisors (Sudan)

O. Extracting four maxillary and four mandibular incisors
(Democratic Republic of the Congo, Uganda)

P. Extracting single lateral incisor (*note:* maxillary *in diagram*) (South Africa)

Q. Artificial prognathism with facially flared maxillary central incisors
(Senegal, Kenya)

The ethnohistoric component of Handler's (1994) hypothesis obscures this possibility and limits the practical relevance of his analysis to those members of the enslaved population that anticipated escape. Thus, runaway advertisements, while useful, are not directly relevant for testing connections between African natality and dental modification for most archaeologically recovered African Diasporan remains. As well, early ethnographic accounts, occupied primarily with describing modification patterns, are of limited use for estimating natality since those patterns often are not geographically confined. Table 6.4 makes this point with respect to modification patterns observed at the ABG. Chemical analyses should more reliably assess the nature of such connections for a greater number of individuals and possibly provide clues for understanding dental modification's limited presence among Diasporan populations.

Geographic natality among enslaved Africans with culturally modified teeth has been chemically estimated before, with low skeletal lead content relative to age interpreted as an indicator of African birth at the Newton Plantation (Corruccini et al. 1987a). More recently, Sealy and colleagues (1995) analyzed bones and teeth to shed light on an understudied dimension of the Transatlantic Slave Trade: Africa's *internal* diasporas produced through involuntary migration. Strontium, carbon, and nitrogen isotopic variation proved useful for establishing non-local origins and dietary patterns of individuals some enslaved and bearing dental modifications, buried during the eighteenth and nineteenth centuries along the coast of Cape Town, South Africa (Cox and Sealy 1997; Cox et al. 2001).

Table 6.4: NYABG Modification Patterns With African and African Diasporan Reference Populations.

Modification Pattern	Burial Number(s)	Referenced Population(s)	Reference(s)
Wave (Incisors and Canines)	47	None	None
Wedge (Central Incisors)	23	Cuba via Congo (Bakongo); SW Angola (Ngumbi); Cape Town via SE Africa (Makua, Maravi and Yao)	Ortiz 1929; Wentzel 1961; Cox and Sealy 1997
Mesial Filing (Incisors)	6, 114, 326, 366, 377	S Angola (Owampo) and N Namibia (Damara); Virgin Islands	von Jhering 1882; Buxton et al., 1938
Distal Chipping/Filing (Incisors)	101, 241,367, 397	Barbados	Handler et al., 1982
I^1, I^2 Mesial, Distal Chipping/Filing	68, 194, 243, 403	Grenada; Cuba via Congo (Loango)	Stewart and Groome 1968; Ortiz 1929
I^1, I^2 Mesial, Distal with C^1 Mesial Chipping/Filing	115, 384	None	None
Point (Incisors)	9, 106, 151, 192	Barbados; Cuba via Congo (Calabar); Gold Coast (Ashanti, Aksin)	Stewart 1939; Ortiz 1929; AMNH
Blunt Point (Incisors)	266, 270, 340	Southern Dem. Republic of Congo	Torday 1919
Hourglass (Incisors)	281	Dem. Republic of Congo; Barbados	Lignitz (1919 – 1920); Handler et al., 1982
General (Occlusal) Chipping/Filing (Incisors)	165	None	None

Modified from Blakey (1998b).

We combine LA- ICP-MS ESA and Sr isotopic analysis to analyze permanent first and third molars (and one central incisor) from a total of 40 "modified" or "non-modified" subadults from the excavated portion of the ABG. ESA is based on the incorporation into enamel of elements that are not nutritionally essential and not directly bioregulated. These nonessential elements may be used to estimate the relative geographic relatedness of individuals during tooth formation and to identify possible clusters among and between modified and non-modified individuals. Since they are not actively physiologically regulated, elements such as lead reflect anthropogenic landscape interactions and patterned pollutant exposure. By comparing early- and later-developing enamel, we are able to more directly consider natal age as well as identify possible migration patterns observed as shifting first and third molar elemental signatures.

This study provides chemical evidence for the estimation of modified and non-modified individuals' natality at the NYABG while piloting the bioarchaeological application of LA-ICP-MS ESA. Cultural dental modification is considered here in biohistorical context, as an archaeologically retrievable biocultural practice. That is, dental modification is viewed as "one of the many ways human populations manipulate and reshape physical features to convey cultural meaning and expression" (Blakey 1998b). Where such practices affect the bones and teeth, they take on added importance for the reconstruction of lived experience.

The NYABG sample is unique in that the number of observable modified dentitions (n = 26) produced by its excavation is the largest associated with an African diasporic population to date. The site is also a window onto colonial Africans' under explored northern experiences. Chemical estimation of natality addresses the first of four

primary questions developed by researchers in collaboration with the skeletal population's descendant (i.e., New York's African American) community: what are the geographic (and/or) ethnic origins of the population? We also implicitly test Handler's (1994) conclusions, based largely on ethnohistorical data, with biochemical analytical methods that are potentially applicable to other African diasporic skeletal populations.

Beyond its absence or presence as a cultural "retention" or "survival," dental modification observed among African diasporans' may provide direct evidence of African natality and childhood and a means of assessing African and American health environments. To date, Handler's (1994) work at the Newton Plantation in Barbados has most thoroughly explored the meaning of African dental modification in the Americas, concluding its presence likely indicates African natality. However, Handler's (1994) hypothesis is limited by its emphasis on escape from enslavement as an impetus to discontinue dental modification. We employ chemical analysis in the form of LA-ICP-MS ESA to estimate African natality among modified and non-modified individuals from the NYABG in an effort to further understand this population's origins and to establish a more widely applicable means of testing Handler's (1994) findings.

Materials and Methods

Sample selection and preparation. LA-ICP-MS ESA was applied to 40 teeth. Thirty-seven from NYABG individuals included a permanent first molar from 13 modified adults and 19 non-modified subadults; a permanent first incisor from 1 modified adult (Burial 101); and a third molar from 4 modified adults. Additionally, an intrusive pig tooth found with Burial 137 was analyzed for its presumably New York values, as were 2

permanent first molars from individuals excavated in coastal Ghana in order to provide possible examples of "West African" trace elemental profiles (see Table 6.5) As we show below, our assumption that the pig tooth came from a local pig is no longer justified based on its high strontium isotope ratio, which suggest that the tooth came from an African born pig.

Table 6.5: NYABG Chemical Analysis Sample.

NYABG modified adult		NYABG non-modified subadult		Ghanaian and other	
ID (age, sex)	Tooth	ID (age, sex)	Tooth	ID	Tooth
Burial 6 (30, M) **Burial 9 (40, M)**	LLM1 LLM1	Burial 7 (4, N/A) Burial 22 (3.5, N/A)	LRM1 LRM1	CREGEG CREGDO	LRM1 LLM1
Burial 23 (21, M)	URM1	Burial 35 (9, N/A)	ULM1	Pig molar associated with Burial 137	Molar
Burial 47 (40, M)	LLM1	Burial 39 (6, N/A)	LRM1		
Burial 101 (32.5, M)	LRI1	Burial 43 (3.5, N/A)	LRM1		
Burial 106 (30, PF)	LRM1	Burial 45 (3.5, N/A)	LRM1		
Burial 115 (30, I)	LRM1	Burial 55 (4, N/A)	URM1		
Burial 165 (35, F)	LLM1	Burial 126 (4.5,N/A)	LLM1		
Burial 266 (30, I)	URM1	Burial 138 (4, N/A)	URM1		
Burial 270 (35, M)	LLM1	Burial 160 (4.5, N/A)	LLM1		
Burial 281 (35, PM)	ULM1	Burial 167 (10.5, N/A)	LRM1		
Burial 340 (19, F)	LRM1	Burial 169 (7.5, N/A)	LRM1		
Burial 366 (35, F)	LLM1	Burial 180 (12, F)	ULM1		
Burial 367 (30, PF)	ULM1	Burial 219 (4.5, N/A)	LRM1		
		Burial 236 (4.5, N/A)	LLM1		
		Burial 244 (7, N/A)	LLM1		
		Burial 286 (6.5, N/A)	LLM1		
		Burial 304 (4, N/A)	LRM1		
		Burial 405 (8, N/A)	URM1		
Burial 9 (40, M)	LRM3				
Burial 47 (40, M)	LRM3				
Burial 101 (32.5, M)	LLM3				
Burial 340 (19, F)	LRM3				

Note that individuals in bold were analyzed for early- and later-forming enamel. Age is given in years.
F (female); PF (probable female); I (indeterminate); PM (probable male); M (male); N/A (not applicable).

Burial 101 was included despite his lack of a permanent first molar because his analysis offers the opportunity to compare chemical findings with skeletal biological data

suggestive of time spent in Africa, i.e., possible evidence of yaws in the form of platycnemia and striated lesions observed for the tibiae. Also, the presence of what appears to be an Akan Adinkra ("Sankofa") symbol tacked to Burial 101's coffin lid reflects perhaps the most ethno-linguistically specific material culture evidence recovered from the site. The Ghanaian individuals were excavated in Eguafo (CREGEG) and Dominase (CREGDO) villages during the summer of 2000 as part of ongoing archaeological research into the dynamics of early West African and European "culture contact" in coastal Ghana's Central Region (see DeCorse 2001).

Sample preparation proceeded as follows. Teeth were first soaked for two days in distilled, deionized water and brushed for removal of loose debris. Organic material was removed with a two-day soak in a 1 percent papain solution, after which teeth were thoroughly rinsed with distilled, deionized water. Following a 30-second, 3 percent (v/v) hydrogen peroxide bath for removal of inorganic material, teeth were rinsed and soaked again for two days in distilled, deionized water. Upon drying, teeth were embedded in Buehler Epoxide Resin with the procedure detailed by Marks et al. (1996). However, teeth were secured in plastic containers with glue instead of copper wire. Two bucco-lingual thin sections approximately .20 – .25 mm in thickness were secured with a diamond-coated copper blade affixed to a low-speed Buehler Isomet cutting unit for histological analysis. The exposed surface of the embedded tooth and the thin sections were etched with 1 M hydrochloric acid. Embedded teeth were polished, cleaned with acetone, and rinsed with distilled, deionized water just prior to ablation. All glassware was cleaned with 50 percent (v/v) nitric acid and rinsed three times with distilled, deionized water.

Sample Collection and Analysis

Selected teeth were ablated with a 266 nm UV pulsed Nd:YAG laser (CETAC, LSX 100, Omaha, Nebraska). Trace elemental intensities (counts per second, or cps) were determined by ICP-MS (Perkin-Elmer Sciex, Elan 6000a, Norwalk, CT). Semiquantitative analytical software (TotalQuant II, Perkin-Elmer, Norwalk, CT) was employed to determine intensities of 64 elements across a mass range of 40.078 (Ca) to 204.383 (Bi), and including 232.038 (Th) and 238.029 (U).

Before laser ablation of each tooth, response factors stored in TotalQuant II were updated to reflect instrument sensitivity under current operating conditions by external calibration with National Institute for Standards and Technology (NIST) standard reference material (SRM) trace elements in glass (612). SRMs are matrices containing certified or known major and trace elemental compositions for a given material used in the development of chemical methods of analysis for trace elements. Certified and known values are both used for calibration in semiquantitative analysis, but only certified values necessarily reflect agreement between two or more methods or laboratories, and thus are more reliable (NIST 1992). The glass matrix (NIST SRM 612) was used because currently there is no enamel hydroxyapatite SRM, which would more closely approximate human tooth elemental composition.

Following optimization of the operating conditions of the ICP-MS for TotalQuant II analysis, calibration and sample collection were performed as follows. First, an argon blank was run as a procedure blank. Next, NIST SRM 612 was ablated as an external standard, with certified/known concentration values of Fe, Ni, Rb, Sr, La, Pb and Th used to construct a calibration curve covering the desired mass range. The NIST SRM 612

was then ablated as a sample, and found and certified/known values were compared in order to evaluate the calibration (Table 6.6).

Table 6.6. ICP-MS external calibration results for NYABG Burial 6 LM_1. Percent of error for elements in bold are below semi-quantitative range (ΔE% +/-30 – 50).

	NIST SRM 612 concentration (ppm by weight)		
Element	Found	Certified/Known	ΔE% error
Ti	0.083	(50.1 ± 0.8)	**-99.83**
Mn	30.175	(39.6 ± 0.8)	-23.8
Fe	46.099	51 ± 2	-9.6
Co	29.121	(35.5 ± 1.2)	-17.969
Ni	33.331	38.8 ± 0.2	-14.095
Cu	33.205	(37.7 ± 0.9)	-11.923
Rb	29.061	31.4 ± 0.4	-7.449
Sr	75.738	78.4 ± 0.2	-3.395
Ag	5.642	22.0 ± 0.3	**-74.36**
Ba	56.424	(41)	37.620
La	32.249	(36)	-10.419
Ce	35.407	(39)	-9.213
Nd	29.498	(36)	-18.061
Sm	26.344	(39)	-32.451
Eu	28.616	(36)	-20.511
Gd	20.648	(39)	-47.056
Dy	19.722	(35)	-43.651
Er	19.931	(39)	-48.895
Yb	23.701	(42)	-43.569
Au	0.146	(5)	**-97.08**
Tl	12.025	(15.7 ± 0.3)	-23.408
Pb	32.957	38.57 ± 0.2	-14.553
Th	13.12	37.79 ± 0.08	**-65.282**
U	4.557	37.38 ± 0.08	**-87.809**

ΔE% error = (Found concentration–certified or known concentration)/certified or known concentration * 100.) = known, but uncertified, value. Certified/known range of concentrations equals larger of entire range of observed results or those within 95% confidence interval (NIST 1992).

Upon verifying accuracy, teeth were ablated as samples. At least two 2.5- to 3-minute raster-pattern ablations were conducted for most teeth, and whenever possible from earliest-formed enamel (i.e., from the cuspal/occlusal area) in order to increase the likelihood of analyzing natal landscape interaction (Figure 6.6). Another calibration was then performed prior to ablation of the next tooth. Counts per second (or intensities) for non-essential, non-bioregulated elements measured within semiquantitative range – Rb, Sr, La, Ce and Pb – were averaged and interpreted with Statistical Package for the Social Sciences (SPSS) 11.0 hierarchical cluster analysis as representations of individuals' relative relatedness. For a detailed discussion of calibration and other theoretical and methodological issues concerning semiquantitative ICP-MS analysis, see Amarasiriwardena et al. (1997), (although their research involved liquid nebulization sampling).

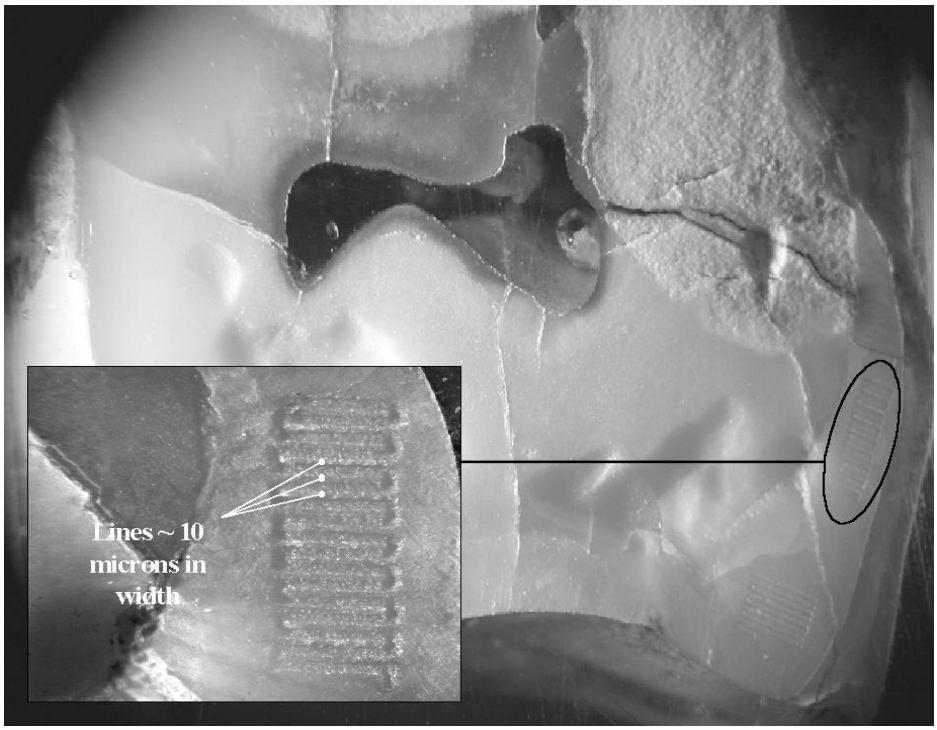

Figure 6.6: Raster ablation (Burial 23, URM1)

Results

The cluster diagram (Figure 6.7) includes the following information from left to right: (a) four main clusters or statistical grouping (C1, C2, B1, A), (b) burial number or sample and tooth sampled, (c) sex, (d) estimated age in years, (e) presence and type of dental modification and (f) finally the cluster-linkages. The lengths of the arms linking the clusters represent the estimated geochemical distance between individuals or groups (clusters). For example, the greatest distance is found between Burial 165 and the remaining individuals.

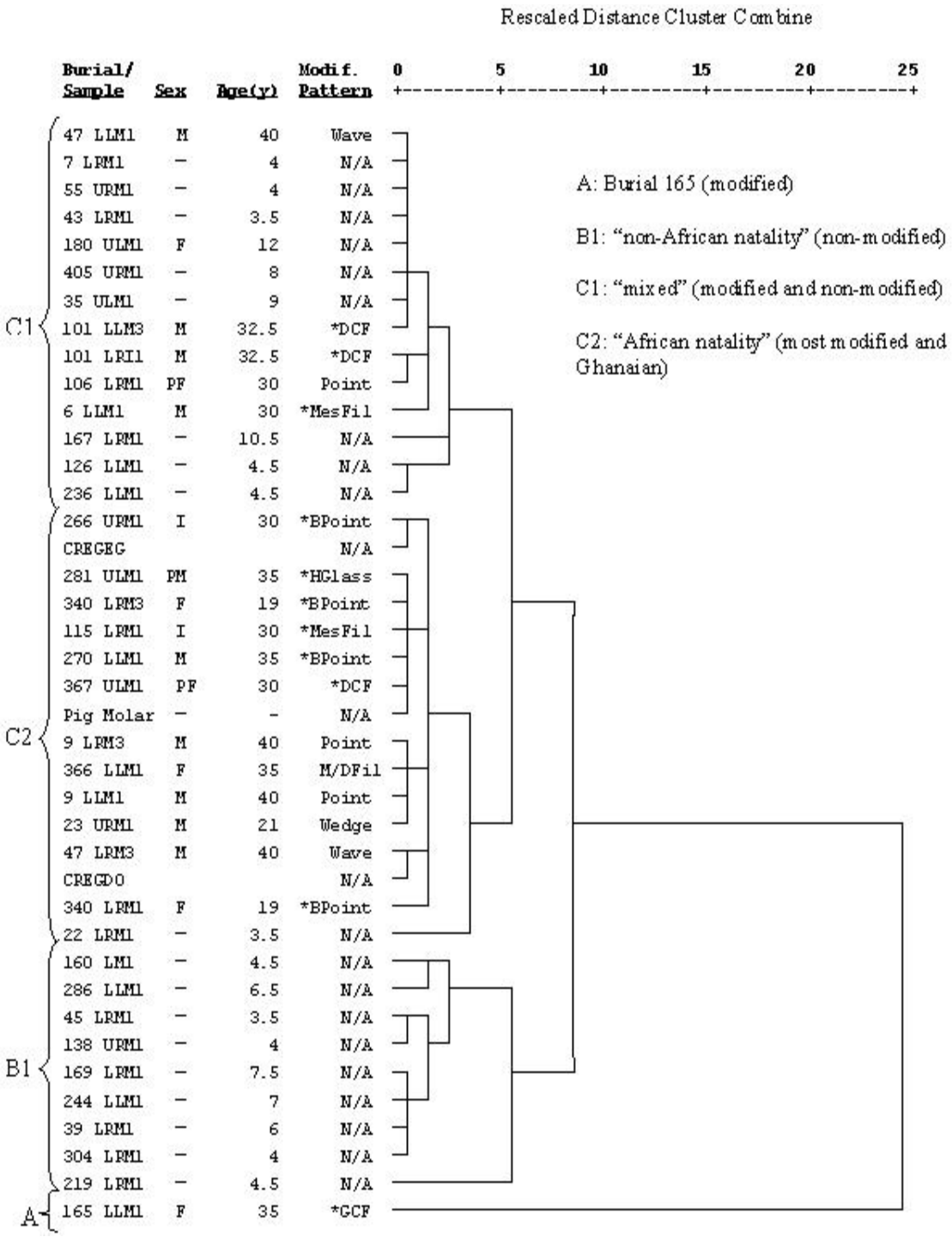

Figure 6.7: ESA Cluster Diagram based on concentrations of five trace elements: Rb, Sr, La, Ce and Pb. BPoint (blunt point); DCF (distal chipping and filing); GCF (general chipping and filing); HGlass (hourglass filing); M/D Fil (mesial and distal filing); MesFil (mesial filing)

As just noted, the analysis produced a first division between Burial 165 (labeled cluster A, bottom) and the remaining individuals are subsequently divided, first separating cluster B1 from the remaining individuals, then subdividing cluster C1 from C2.

The interesting result concerns which individuals were designated to each cluster. Cluster B1 consists of nine teeth/individuals, from Burial 160 to Burial 219. All of these individuals died before eight years of age. Cluster B1 appears to be a natal New York cluster.

Cluster C2 includes fourteen individuals and sixteen teeth starting with Burial 266 and ending with Burial 22. The sixteen teeth include two teeth from Ghana, the intrusive pig molar, and thirteen teeth, and eleven individuals from the burial ground. Two individuals, Burial 9 and Burial 340 are represented by both an M1 and an M3 and with the exception of Burial 22 at the bottom of the cluster; all of the other twelve ABG individuals display dental modifications. These results suggest that this is an African natality cluster.

Cluster C1 is more mixed than the others. There are fourteen teeth and thirteen individuals in this cluster (Burial 101 is represented by two teeth). The majority of the teeth, nine individuals/teeth, are from children without dental modifications. Five other teeth are from four individuals (Burial 47, Burial 101, Burial 106 and Burial 6) with CMT. Finally, Burial 47 is represented in this cluster by its first permanent molar and in the C2 (African natal) cluster by its third permanent molar. This cluster switch is intriguing as it suggests a movement from a yet unknown area.

In summary, ESA, a first methodology, has successfully separated the majority of individuals/teeth into coherent clusters. This helps affirm the utility of the method, on one hand, and that young individuals were indeed born near New York while the majority of individuals with modified teeth were African born.

A key implication of these data is that, depending on how they cluster, it may now be possible to determine the broad geographic natality of older individuals without modifications. However, some interesting questions remain before we can take this next step with confidence. Why does Burial 22, an individual that died at 3.5 years of age, cluster with African born individuals? And why do four individuals with dental modifications cluster with nine young individuals without modifications? One complication is that the chemistry of a first molar may partly reflect the chemistry of the mother's environment if the mother loses bone apatite during breast-feeding. Another hypothesis is that dental modification continued in New York. Our hope is that another method will help resolve alternative hypotheses.

Strontium Isotope Ratios

As previously noted, the ratio of ^{87}Sr to ^{86}Sr has emerged as a powerful method to distinguish the age of landscapes. Because the isotopes are not fractionated in biological tissues, the tissues of animals living on these landscapes reflect the landscapes.

Methods and Materials

As in the ESA analysis, for this pilot or testing study we selected teeth from dentally modified individuals as well as teeth of young individuals from the NYABG. In most cases, analyses focused on the first permanent molars, which develop during the first few years of life. All samples were obtained by drilling dentine and enamel using a

Dremel tool and stainless steel bits (Figure 6.8). The bit was thoroughly cleaned with water in an ultrasonic bath and visually inspected under a microscope for contamination between samples. Analyses of replicate drill samples from the same tooth suggest contamination by the bit and cross-contamination between samples was negligible. Powder was collected and placed in an ultraclean teflon beaker with approximately 1 mL of 7M HNO_3. The beaker was sealed and placed on a hotplate at 100˚C overnight for dissolution. After cooling, the beakers were opened, returned to the hotplate and evaporated to dryness. The sample was cooled and dissolved again in 600 µL 3.5M HNO_3 in preparation for isolation of Sr. All samples were centrifuged prior to column chemistry; however, no solid residue was ever observed. Strontium was separated using standard, Sr-specific crown-ether resin chromatagraphic techniques. Columns used had a

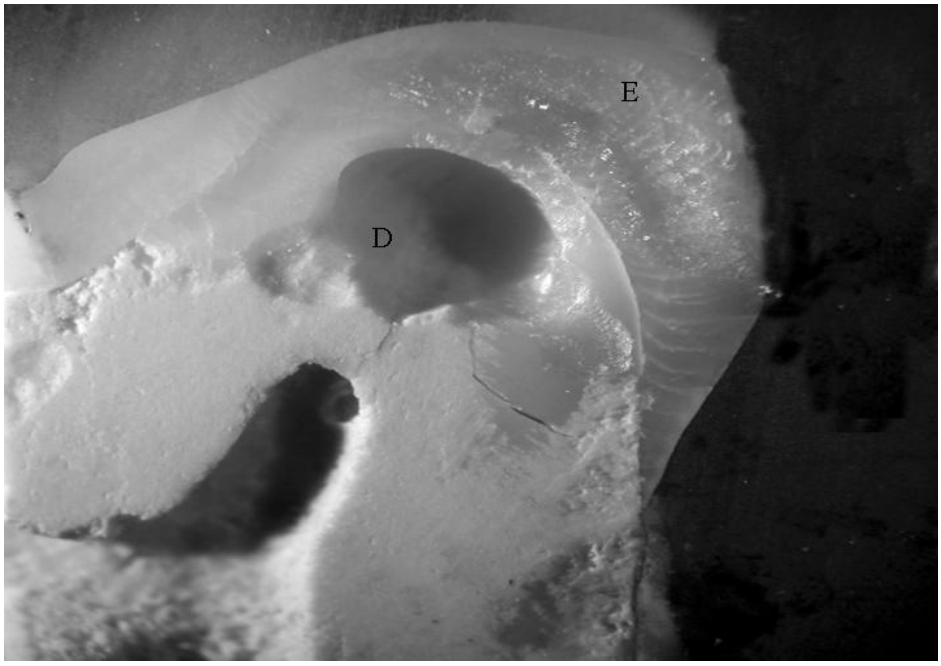

Figure 6.8: Dremel Drill drilling (Burial 266, LRM1). D = dentine, E = enamel.

total column volume of approximately 35 µL. Rinsing was done with 3.5M HNO_3, and Sr was eluted with water. Total procedural blanks during analysis were less than 100 pg

Sr and comprise a negligible portion of the Sr analyzed. Separated Sr was dried in H_3PO_4 and loaded onto single Re filaments using a $TaCl_5$ emitter solution for analysis. Analysis was accomplished on a VG Sector (University of Kansas analyses) and Sector-54 (University of North Carolina, Chapel Hill analyses) thermal ionization mass spectrometer. Both labs use identical 3-cycle dynamic Sr analysis routines and all data are normalized to $^{86}Sr/^{88}Sr = 0.1194$. Replicate analyses of NIST-987 yield $^{87}Sr/^{86}Sr = 0.710262 \pm 0.000009$ (2σ).

Results

Results are reported as the ratio of ^{87}Sr to ^{86}Sr (Figure 6.9). Although results appear to tightly cluster around 0.710-0.720, the method is accurate to six significant figures. Thus, it may eventually be possible to suggest that a difference as small as 0.710450 to 0.710460 is meaningful.

Figure 6.9 provides a summary of results. The $^{87}Sr/^{86}Sr$ ratio is plotted on the y-axis and individuals span across the x-axis. Approximate ages are at the bottom and in boxes are the individuals' $^{87}Sr/^{86}Sr$ ratios with enamel represented by open circles and dentine represented by dark diamonds. Individuals lacking decorative modifications are on the left; individuals with decorative modifications are toward the center, and the Ghanaian teeth, Ghanaian well water, and the intrusive pig molar are located on the right.

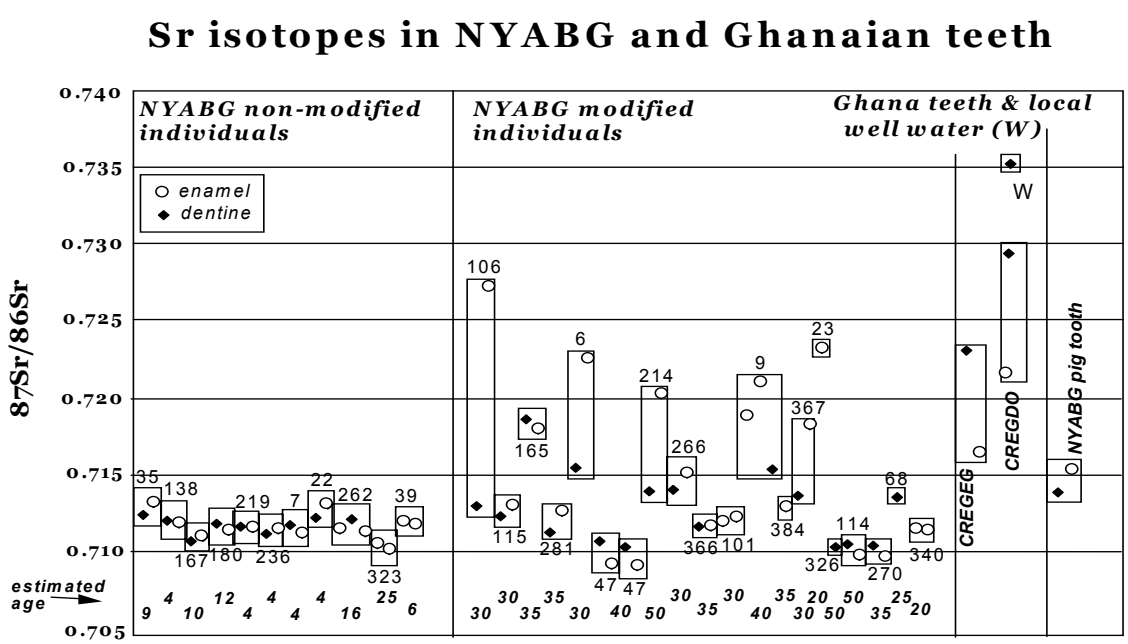

Figure 6.9: Strontium Isotopes Chart: Ratio of ^{87}Strontium to ^{86}Strontiumin samples of enamel and dentine of individuals from the New York African Burial Ground, plus two individuals from Ghana; water from Ghana; and an intrusive pig molar (recovered with Burial 137).

Enamel

Based on prior geological studies and the clustering of young individuals, the "local" Manhattan $^{87}Sr/^{86}Sr$ value is likely to be ~0 .711-712. And, in fact, most young and non-modified individuals (left side of figure) have both enamel and dentine values that cluster around in this range.

On the other hand, the Ghanaian teeth and waters and the intrusive pig have much higher $^{87}Sr/^{86}Sr$ values. The highest $^{87}Sr/^{86}Sr$ found was from a river sample collected in Ghana (value over 0.735). All of these samples have significantly higher strontium isotope ratios than those found in the New York born and suggest a wide range of values in Africa. These results are consistent with prior findings.

The individuals with decoratively modified teeth seem to divide into two or even three groups. Many individuals have high enamel values (Burials 106, 165, 6, 214, 266,

9, 267 and 23). Others such as Burial 47, Burial 114 and Burial 270 may be below the Manhattan value and others (Burials 115, 281, 366 and 101) are at the moment indistinguishable from the Manhattan value.

Dentine vs. Enamel

Dentine values relative to enamel values provide some potential insights. In all of the young individuals without dental modification, the dentine values are close to the enamel values, suggesting little movement or migration during life. On the other hand, the Ghanaian dentine values are high relative to the enamel values, suggesting possible movement to the African interior.

Most interesting is that all individuals with enamel ratios above the suggested "Manhattan range" have dentine values that are *closer* to the Manhattan range. This suggests that dentine may be chemically equilibrating to the lower Manhattan range. Possible explanations for this movement of dentine toward the Manhattan range might be either postmortem diagenesis, the incorporation of vital secondary dentine, or changes in primary dentine chemistry during life. In the future we intend to test among these different explanations because they have different implications for the interpretation of dentine chemistry.

Enamel Strontium Isotopes Ratios compared to ESA

The combined results of two independent sourcing methods suggest the following. First, the vast majority of young individuals cluster together in both methods. This suggests that they indeed spent all of their short lives in and around New York.

Similarly, most individuals with modified teeth cluster together in both the ESA and strontium isotope studies, suggesting that they spend their early lives in Africa.

A few individuals particularly require further study by more detailed examination of sequentially developing enamel and dentine by the above methods and new methods. For example, Burial 101 falls within the range of the New York-born on both methods, suggesting the possibility that this individual's teeth were modified in the Americas. On the other hand, Burial 106 clearly appears to be African born based on strontium isotopes, but not based on ESA.

Enamel Lead Content

As part of the collection of data for ESA, data were collected semi-quantitatively for nutritionally significant elements such as strontium and iron and heavy metal pollutants such as lead. Here we provide a brief note on lead variation within the ABG teeth.

Figure 6.10 presents lead intensities for samples with dental modifications (dark bars) and other individuals. Intensities are ordered from lowest to highest and vary from near nonexistent (less than 100 counts per second) to over 50,000 counts per second. The average intensities of lead in non-modified teeth are over 30,000, compared to an average of fewer than 5000 counts per second for modified individuals.

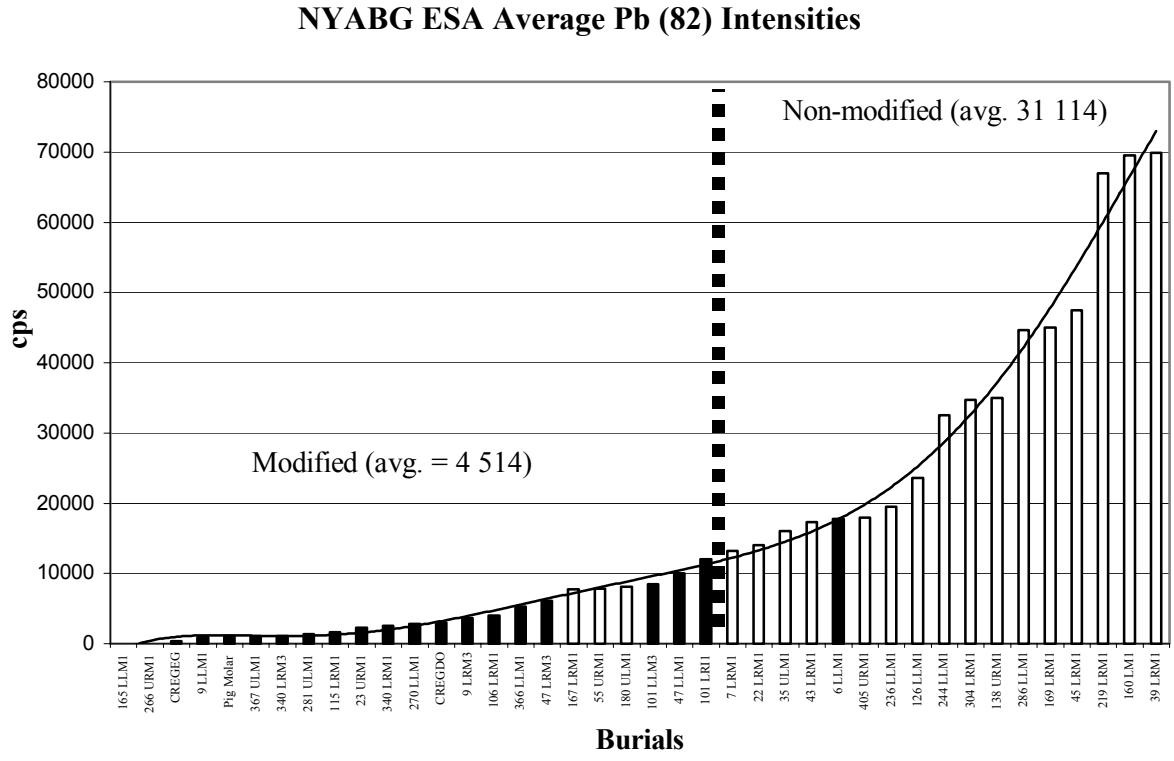

Figure 6.10: Lead Variation. Ranking of intensities of lead in teeth studies for ESA. Teeth from individuals with dental modifications (dark bars) tend to have low lead levels compared to individuals without dental modifications (white bars).

Without doubt, lead is significantly high in the teeth of some individuals from the ABG. As part of a broader study, six individuals were analyzed quantitatively for lead concentrations by liquid nebulization-ICP-MS (Webb et al., 2003). Despite the small sample size, it is worth noting that two non-modified children's (Individuals 304 and 405) whole tooth lead levels were significantly higher than those of four modified adults (Individuals 47, 266, 340 and 367). Lead levels ranged from 1.2 to 112.2 μg/g (ppm), observed in Individuals 405 and 367, respectively. While it is as yet unclear precisely how lead levels of (different regions in) teeth relate to blood levels, 10 μg/dL in blood is above the Centers for Disease Control (CDC) threshold for unsafe lead levels. A

concentration in whole teeth of over 100 ppm is undoubtedly unsafe and would have neurological and behavioral consequences (Purchase and Fergusson 1986).

Lead burden variation observed in the ABG sample underscores the need to assess the distribution and biohistorical impacts of elevated lead burden within and across populations. For example, enslaved African bone lead levels were apparently more variable and generally higher in Barbados than in at least some parts of southern mainland North America. Corruccini *et al.* suggest that many enslaved Africans buried at the Newton Plantation experienced *"only mild, intermittent symptoms of lead intoxication*…[while others] *probably suffered moderate to severe symptoms*" (1987a: 238). Aufderheide et al. (1981, 1988) associate high bone lead values from the Clifts Plantation in eighteenth century Virginia primarily with wealthy white slaveowners who ingested "very substantial" quantities of lead via foods stored in relatively expensive, pewter containers. Likely also affected, however, were domestic laborers whose access to such foods and subsequent lead burden would have been greater than that of other enslaved Africans; possibly the explanation for high lead content observed for an 18 year-old female (Aufderheide1988). Rathbun (1987) reports mean bone lead values intermediate to those from the Caribbean and Virginia studies for African American remains excavated from a nineteenth century plantation cemetery in Charleston, South Carolina.

As lead is found in enamel formed during the first year or two of life, the public health significance of better understanding the social and biocultural etiology and consequences of lead poisoning becomes even clearer. It is highly likely that lead is transmitted from mother to child through breast-feeding and may even be transmitted

prenatally (Schell 1991, 1997). Thus, the distribution of elevated lead levels is in part a reflection of maternal lead burden—a "multigenerational experience" (Schell 1997: 72) historically and organically linked to race, residence and economic status in the United States. Hence, lead poisoning is no longer an "unrecognized" epidemic affecting primarily white landowners. Today, lead poisoning constitutes a "silent" epidemic disproportionately affecting African Americans "hypersegregated" in low-income, urban areas where malnutrition, old housing and prolonged exposure due to low social mobility maximize lead levels (Lanphear et al. 1996; Needleman 1998; Reed 1992; Weintraub 1997).

This finding of unusually high lead levels among first-generation African Americans, especially in individuals who died at an early age in New York, provides important historical context and leads to a number of important questions. We would like to know the prevalence of lead pollution, the source of the pollution, the age of individuals who are ingesting high lead levels, and whether lead is implicated in their early deaths. Expanded lead analysis may help to distinguish other groups within the NYABG sample whose work environments or status placed them at higher risk for lead poisoning. These would include domestic workers, mine workers, and possibly freed people; some of whom would have had greater access to pewter items (see Aufderheide et al., 1985; McCord, 1953).

Conclusions

Preliminary studies of teeth from individuals buried in the NYABG confirm that most individuals who died at an early age spent their lives in and around Manhattan and most individuals with culturally modified teeth appear to have spent their first decades

somewhere in Africa. Strontium isotopes also suggest that a few individuals may have spent time in the Caribbean. High lead level in teeth of individuals who lived their lives around Manhattan and died at an early age is an entirely new finding.

These pilot studies have significantly furthered our understanding of the lives of the individuals who are buried in the NYABG. The results strongly hint at the capability to tell the geographic histories of individuals along with individual histories of nutrition and pollution exposure. Combined with historical, archaeological, and other bioarchaeological information, additional studies modeled on the ones conducted here will lead to the clearest understanding of enslaved Africans.

Therefore, based on the outcomes obtained in these pilot studies and the experience gained from research on the ABG sample, the ABGP Skeletal Biology team intends to pursue additional funding for the conduct of future studies that would explore, among others, the following:

- Extension of studies to bone to better understand chemical conditions nearer the time of death.
- Establish the cause of variation in chemistry between enamel and dentine of the same tooth.
- Extensive analysis of soils and fauna from New York and possible other natal homes (West Africa, Caribbean) in order to better establish values at possible source locations.
- Extension of analyses to other teeth and a finer grained analysis of teeth.
- The addition of new methodologies such as oxygen isotopes to further resolve natal homes.

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